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A profound study on the effects of friction coefficient on torque tightened, longitudinally loaded, bolted connections

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Abstract: Friction coefficient between different surfaces of bolted connections plays an important role, since it is the most contributing factor in transferring the applied external loads. The main contribution of this paper is in a numerical study on the effects of friction coefficient on the resulting initial and final clamping force in bolted connections, before and after being loaded longitudinally. In the analysis a full, precise, (3D) finite element simulation of a bolted connection assembly, without any simplifications, was performed using the new and state of the art ANSYS package platform called ANSYS WORKBENCH. Then, the assembly was loaded with 2 tangential forces on two opposing sides of the nut's hexagonal faces, which generated a 7N.m torque around the center of the bolt, and the resulting clamping force was calculated. The results, showed that the five different counteracting surfaces of the model, each contribute to the resulting clamping force differently. The friction coefficients in nut-nut washer -as the factor which determines the proportion of the external force to be passed to other parts- and bolt head-bolt head washer as a support which keeps the clamping force inside-regions affected the resultant clamping force more than the others.

Keywords: friction coefficient, clamping force, bolted joint, numerical investigation, finite element modeling

Introduction:

Huge structures are an inevitable and inseparable part of mechanical and aerospace structures as well as the diverse types of connections, which are used in the assembling process of them. The efficiency and advantages of bolted connections as one of the most widely used of them, including separability in case of a need for maintenance, to reach to the underlying parts of an airplane, for example, and changing a single area of a part which is prone to disaster structurally, is not covered to anyone. A vital, aiding factor in these connections, which leads to a better life, due to some compressive stresses it generates around the hole of the plate, is the clamping force or preload. This force is generated as a result of the process of

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tightening the nut over the bolt, which squeezes the plate or plates between them. The more the tightening torque (so the clamping force), the more the compressive stresses appear, which confront with the certain upcoming longitudinal stresses, leading to a more sustainable connection and a better life (1). Surfaces of the parts are in contact to form these connections, and friction coefficient as a factor which determines the proportion of the applied external force to be conveyed through two surfaces, plays an important role in them; therefore, knowing the most contributing and effective of them in a bolted connection determines where to reduce the friction coefficient in order to obtain more clamping force or beneficial compressive stresses around the hole of the holed plate.

Previous studies revealed the detrimental effect of lubricating the clamped plate or reducing its friction coefficient on fatigue life, since it increases the proportion of bearing load transferred via bolt shank and therefore, higher detrimental stresses appear around the hole, which cause it to fail sooner. In other words, the more slippery that the surface becomes, the more bearing load appears in bolt shank, which is not desiring from a clamping and thus fatigue point of view (2-4). In some researches factors that influence the friction coefficients in bolted connections were tested, including material type and environmental factors, while the others investigated its beneficial effects on clamping force experimentally and simply, but not distinctively on each surface of the assembly (5) (6).

An apparent conclusion is that none of them has discussed the impacts of each of the aforementioned friction coefficients in these bolted connections distinctively. This paper profoundly discusses and scrutinizes the effects of friction coefficients on clamped bolted plates' initial clamping force magnitude and the one after being loaded longitudinally. To do so, a full and precise finite element model of the assembly was created and the real condition of the loading was simulated. Graphs that show the effect of each increase and decrease in friction coefficients of each of the five types of frictional contacts were also drawn. Finally the most contributing friction coefficients and the best combination of them were presented, to achieve the desiring clamping force in a more efficient and easier way, with a less amount of required torque and less reduction after being loaded longitudinally.

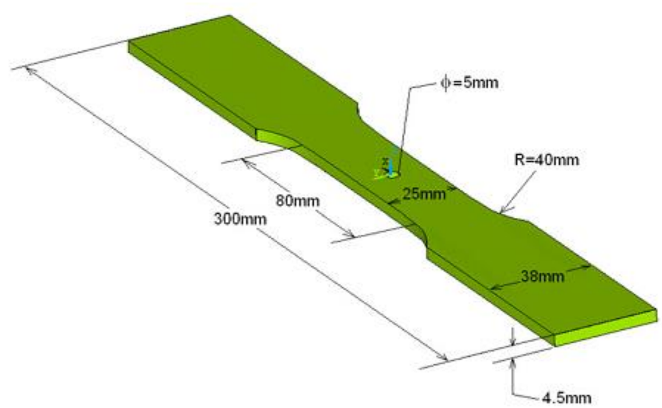

Figure 1. Plate dimensions (10)

Finite element modeling

The analyzed model constitutes of an M5×0.8 bolt, M5×0.8 nut, two washers and a plate with the dimensions illustrated in Figure 1. The plate's material is aluminum alloy 7075-T6 which is modeled with a

nonlinear kinematic hardening plasticity model. The others are made of steel and modeled with a linear elastic behavior, since they remain within the elastic region with a 7N.m torque (1).

To achieve the best solution possible and the closest one to the real condition, a full, thread-included model of the bolt and nut was created based on the ASTM standards for bolts and nuts. The connections of the coinciding faces of the five parts of the assembly - bolt head and bolt head washer, bolt head washer and plate, plate and nut washer, nut and nut washer, bolt thread and nut thread - were modeled utilizing ANSYS WORKBENCH frictional contacts, which allow the surfaces to slide, but not to separate.

ANSYS (3D) solid element type of SOLID185 was chosen and used, for generating a mapped mesh on the model. This element is used for the three-dimensional modeling of solid structures and is defined by eight nodes having three degrees of freedom at each node: translations in x, y, and z directions. The element has plasticity, stress stiffening, large deflection, and large strain capabilities (7). CONTA174 and TARGE170 element types were also used in the areas of contact. This element is used to represent contact and sliding between 3-D "target" surfaces (TARGE170) and a deformable surface, defined by it. The element has three degrees of freedom at each node: translations in x, y, and z directions and has the same geometric characteristics as the solid or shell element face with which it is connected to. Contact occurs when the element surface penetrates one of the target segment elements (TARGE170) on a specified target surface. Coulomb and shear stress friction is also allowed (8). It's worth mentioning that a thorough investigation and trial and error method was used in the analysis on the effects of element type and size, along with drawing some graphs to maintain a solution, independent of mesh size and properties.

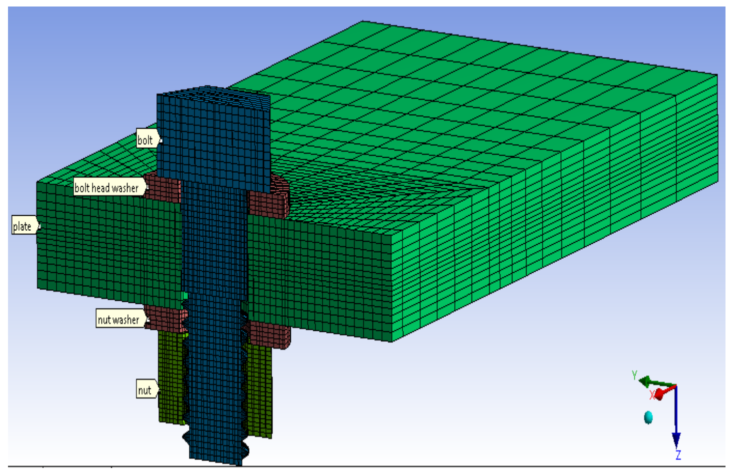

Figure 2. Finite element, meshed model

Three friction coefficients with the magnitudes of 0.05, 0.15 and 0.3 were utilized in order for each one of the five frictional contacts at a time, while the others were fixed on a magnitude of 0.15, to observe the effects of a decrease or increase in one's friction coefficient on resulting clamping force, separately. First, the model was loaded with two tangential forces on two opposing sides of the nut's hexagonal faces, which created a 7N.m tightening torque. Second, a 240MPa longitudinal tensile load was applied at the end of one transversal side of the plate to investigate the impacts on clamping force reduction, which happens in bolted connections after being subjected to longitudinal tensile load (9). Finally, different stress contours were plotted and the magnitude of clamping force was estimated.

Finite element analysis results

The change in initial clamping force against an increase in friction coefficients of each of the frictional connections of the assembly -under a constant external 7N.m torque -as elaborated in previous section of the paper- is depicted by a graph in Figure 3. The graph apparently shows that an increase in friction coefficient between bolt head and bolt head washer, and a decrease in the magnitude of friction coefficient between nut and nut washer, leads to an increase in initial clamping force. Generally, in one hand, it is better to have a lower friction coefficient at the bottommost frictional surface -the one between nut and nut washer-, since it is that surface, which determines the proportion of the external force to be entered to the assembly, just like a thermocouple which allows for a specific amount of temperature to be inside a mechanism; on the other hand, it is better to have a higher magnitude of friction coefficient in the laying surface between the bolt head and bolt head washer, as the topmost frictional surface, since this one roles as a support, which confronts with the incoming applied torque to keep the force inside; therefore the more the friction coefficient in here, the higher the initial clamping force.

Consequently, moving from the bottommost frictional surface to the topmost one and by increasing the friction coefficient, the resulting initial clamping force at the friction coefficient of 0.3 approximately starts to become closer and even more than its corresponding value at the friction coefficient of 0.05. The same change and increase -as shown is Figure 3- is shown in Figure 4, but this time against the final clamping force after pulling the plate longitudinally.

Evidently, an increase in the magnitude of friction coefficient for nut-nut washer, nut washer-plate and bolt washer-plate contact regions, smoothly decreases the amount of initial clamping force reduction or compressive stresses reduction around the hole, which is desiring.

Stress magnitudes through half thickness of the plate on the edge of its hole, after being loaded longitudinally, are plotted against half

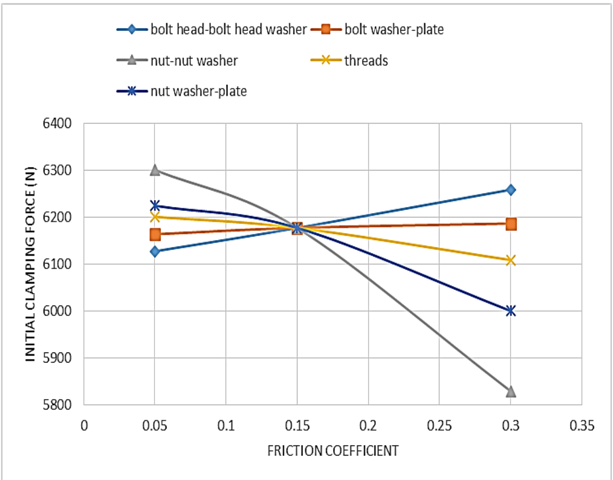

Figure 3. Initial clamping force variations against friction coefficients for different frictional contact regions

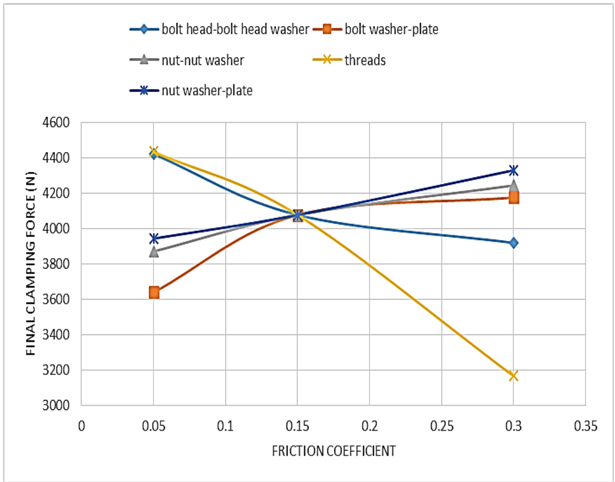

Figure 4. Final clamping force variations against friction coefficients for different frictional contact regions

thickness length in Figure 5. Half thickness is a vertical line starting from the middle of the plate depth, on the periphery of the hole, up to the top surface of the plate, where the plate and the bolt head washer meet. As it is evident in the graph, having the topmost friction coefficient of the simulation, which is 0.3, in the bolt head washer and plate contact region leads to lower magnitudes of positive detrimental stresses around the hole and the best graph of all. In contrast, having the lowest friction coefficient of the

simulation in there, which is 0.05, leads to the worst case of the graphs or having the highest magnitude detrimental stresses around the hole, which are known to be destructive from a fatigue life point of view. Also, the two other beneficial friction coefficients from clamping view point -0.3 for bolt head-bolt head washer and 0.05 for nut-nut washer- lay in the good region of the graph and lead to less detrimental stresses around the hole.

Nomenclatures

μ Friction coefficient

F_{cl} the resultant clamping force in bolt shank due to applied tightening torque

Greek symbols

σ Normal stress

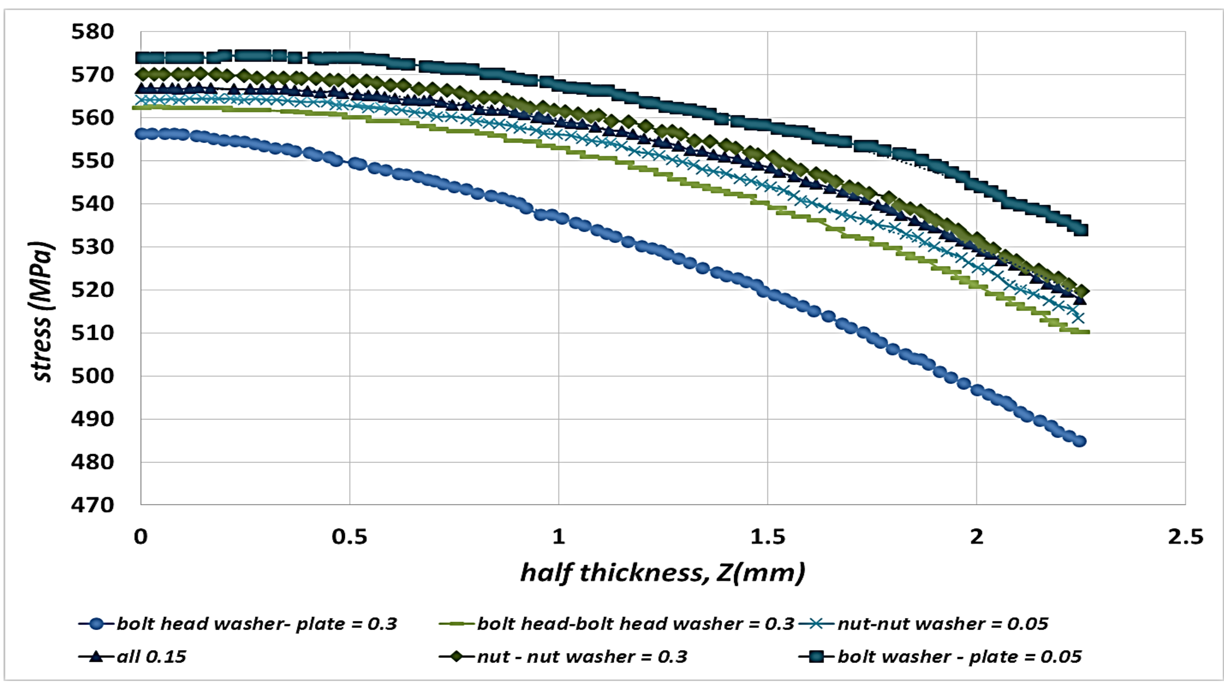

Figure 5. The distribution of σ_x through the plate half thickness at the hole edge

Conclusions

- By increasing the friction coefficients, while moving from the bottommost region of the assembly to the topmost one, the magnitude of initial clamping force in 0.3 friction coefficient becomes closer and even higher than its corresponding value in 0.05 friction coefficient.
- Increasing the friction coefficient in bolt head-bolt head washer region results in a higher initial clamping force in bolt shank.
- Increase in friction coefficients of the nut-nut washer, nut washer-plate and bolt washer-plate contact regions leads to a less reduction in beneficial clamping force after being loaded longitudinally.
- A combination of 0.3 friction coefficient for the bolt head-bolt head washer contact region, 0.05 friction coefficient for the nut-nut washer contact region and 0.15 friction coefficient results in the highest initial clamping force, less reduction in that and the lowest detrimental stress range around the hole.

References and Notes:

[1] T.N.Chakherlou, R.H. Oskouei, J. Vogwell, 2007 “Experimental and numerical investigation of the effect of clamping force on the fatigue behavior of bolted plates”. Engineering Failure Analysis 15 (2008) 563–574.

[2] T.N. Chakherlou, M.J. Razavi, B.Abazadeh 2012 “Finite element investigations of bolt clamping force and friction coefficient effect on the fatigue behavior of aluminum alloy 2024-T3 in double shear lap joint”, Engineering Failure Analysis 29 (2013) 62–74

[3] E. Hemmati Vand, R. H. Oskouei, T. N. Chakherlou, 2008 “An Experimental Method for Measuring Clamping Force in Bolted Connections and Effect of Bolt Threads Lubrication on its Value”, World Academy of Science, Engineering and Technology Vol:2 2008-10-25T.N.

[4] H.E.M. Sallam, A.E.A. El-Sisi, E.B. Matar, O.M. El-Hussieny, 2011 “Effect of clamping force and friction coefficient on stress intensity factor of cracked lapped joints”. Engineering Failure Analysis 18 (2011) 1550–1558.

[5] D. Croccolo, A. Freddi, M. De Agostinis, N. Vincenzi, 2010 “Experimental study of friction in aluminum bolted joints”, D. Croccolo et alii, 9th YSESM, Trieste, Italy, July 7-9, 2010; ISBN 978-88-95940-30-4

[6] Bachelor’s thesis, Jacob Mortensen., 2013. “Friction Analysis of Bolts”. Bsc Thesis, Aalborg Universitet Esbjerg. See also URL http://www.en.esbjerg.aau.dk.

[7] ANSYS Release 15 Documentation, ANSYS Elements Reference, Element Library, SOLID185.

[8] ANSYS Release 15 Documentation, Theory Reference, Chapter 14, Element Library, CONTAC174.

[9] R.H. Oskouei, T.N.Chakherlou, 2009"Reduction in clamping force due to applied longitudinal load to aerospace structural bolted plates". Aerospace Science and Technology 13 (2009) 325–330.

[10] T.N.Chakherlou, M. Mirzajanzadeh, J.Vogwell, B.Abazadeh, 2010 "Investigation of the fatigue life and crack growth in torque tightened bolted joints". Aerospace Science and Technology 15 (2011) 304–313.